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A dependence domain for a class of micro-differential equations with involutive double characteristics

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1 Statement of the Main Theorem

Let M be a real analytic manifold with a complex neighborhood X . Let P be a microdifferential operator defined in a neighborhood U in T^*X of $\dot{q} \in T_M^*X \setminus M$. We assume that the characteristic variety of P satisfies

$$\text{Char}(P) \subset \{q \in U; p_1(q) \cdot p_2(q) = 0\}$$

with homogeneous holomorphic functions p_1 and p_2 on U . We assume that

$$p_1 \text{ and } p_2 \text{ are real valued on } T_M^*X, \quad (1)$$

$$dp_1 \wedge dp_2 \wedge \omega_X(q) \neq 0 \text{ if } p_1(q) = p_2(q) = 0, \quad (2)$$

$$\{p_1, p_2\}(q) = 0 \text{ if } p_1(q) = p_2(q) = 0. \quad (3)$$

Here ω_X is the canonical 1-form of T^*X , and $\{\cdot, \cdot\}$ the Poisson bracket on T^*X .

In this situation, we can define a regular involutive submanifold V by

$$V = \{q \in U; p_1(q) = p_2(q) = 0\}.$$

We assume, for simplicity, that $\dot{q} \in V$. Moreover Γ denotes the canonical leaf of V passing through \dot{q} .

A set K in Γ is called, in this article, a Γ -rectangle if there exists an injective real analytic map

$$\Phi : [0, 1] \times [0, 1] \longrightarrow \Gamma$$

with the following three properties.

- $\Phi([0, 1] \times [0, 1]) = K$

- $\Phi(\cdot, t)$ is an integral curve of the Hamiltonian vector field H_{p_1} for any fixed $t \in [0, 1]$.
- $\Phi(s, \cdot)$ is an integral curve of the Hamiltonian vector field H_{p_2} for any fixed $s \in [0, 1]$.

We give, in this situation,

Theorem 1.1 *There exists an open neighborhood U_0 of \dot{q} in Γ with the property that for any Γ -rectangle K contained in U_0 with the four vertices q_0, q_1, q_2 , and q_3 and for any microfunction solution u to $Pu = 0$ on K ,*

$$q_1, q_2, q_3 \notin \text{supp}(u) \implies q_0 \notin \text{supp}(u).$$

This theorem can be deduced from the model case given in the next section, where several remarks are also given.

2 Theorem in the model case

Let M be an open subset of \mathbf{R}^n with a complex neighborhood X in \mathbf{C}^n ($n \geq 3$). We take a coordinate system of M (resp. X) as $x = (x_1, \dots, x_n)$ (resp. $z = (z_1, \dots, z_n)$). Then $(x; \sqrt{-1}\xi \cdot dx)$ (resp. $(z; \zeta \cdot dz)$) denotes a point in T_M^*X (resp. T^*X) with $\xi = (\xi_1, \dots, \xi_n)$ (resp. $\zeta = (\zeta_1, \dots, \zeta_n)$).

We take a point $q_0 = (0; \sqrt{-1}dx_n) \in T_M^*X$. Let P be a microdifferential operator defined in a neighborhood of q_0 whose principal symbol is of the form

$$\zeta_1^{m_1} \zeta_2^{m_2}$$

with $m_1, m_2 \geq 1$. We define an involutive manifold V of T_M^*X by

$$V = \{(x; \sqrt{-1}\xi \cdot dx); \xi_1 = \xi_2 = 0\}$$

and denote by Γ the leaf of V passing through the point q_0 . We take a rectangle K on Γ defined by

$$K = \{(x_1, x_2, x'' = 0; \sqrt{-1}dx_n); 0 \leq x_1 \leq t_1, \quad 0 \leq x_2 \leq t_2\}.$$

The vertices of K are denoted by

$$\begin{aligned} q_0, q_1 &= (t_1, 0, 0; \sqrt{-1}dx_n), \quad q_2 = (0, t_2, x'' = 0; \sqrt{-1}dx_n), \\ q_3 &= (t_1, t_2, x'' = 0; \sqrt{-1}dx_n). \end{aligned}$$

Here $x'' = (x_3, \dots, x_n)$. Then we have

Theorem 2.1 *Let u be a microfunction defined in a neighborhood of K . We assume that u satisfies*

$$Pu = 0$$

and that the three points q_1, q_2, q_3 are not in $\text{supp}(u)$:

$$q_1, q_2, q_3 \notin \text{supp}(u).$$

Then

$$q_0 \notin \text{supp}(u).$$

Remark 2.1 *The phenomenon in the above theorem was first observed by Y. Okada[O] for C^∞ wavefront set of microdistribution solutions. His result concerns with the case $m_1 = m_2 = 1$ under a Levi condition on the lower order term of P . He employed a microlocal version of Goursat problem in the complex domain.*

Remark 2.2 *It is inevitable to assume the condition $q_3 \notin \text{supp}(u)$ in Theorem 2.1 For example, we define a hyperfunction*

$$u(x_1, x_2, x_3) = (Y(x_1) - Y(x_2)) \cdot \delta(x_3),$$

which is a solution to $D_1 D_2 u = 0$. Then we have, for a positive constant $t > 0$,

$$q_1 = (t, -t, 0; \sqrt{-1}dx_3), q_2 = (-t, t, 0; \sqrt{-1}dx_3) \notin \text{supp}(u),$$

but

$$q_0 = (t, t, 0; \sqrt{-1}dx_3), q_2 = (-t, -t, 0; \sqrt{-1}dx_3) \in \text{supp}(u).$$

To give an implication of Theorem 1.1, we recall a result obtained by N. Tose [T2].

Theorem 2.2 *Let u be a microfunction solution to $Pu = 0$ on an open subset U of Γ . Then there exist a family $\{b_\lambda^{(1)}\}_{\lambda \in \Lambda_1}$ of integral curves on Γ of $\partial/\partial x_1$ and another family $\{b_\lambda^{(2)}\}_{\lambda \in \Lambda_2}$ of integral curves on Γ of $\partial/\partial x_2$ which satisfy the property that $\text{supp}(u)$ has unique continuation property on the set*

$$\Omega = U \setminus \left(\bigcup_{\lambda \in \Lambda_1} b_\lambda^{(1)} \cup \bigcup_{\lambda \in \Lambda_2} b_\lambda^{(2)} \right).$$

More precisely, if a point $q \in \Omega$ is not in $\text{supp}(u)$, then the connected component of Ω containing q is disjoint with $\text{supp}(u)$.

In the situation of Theorem 2.2, we take a point

$$\dot{q} = (s_1, s_2, x'' = 0; \sqrt{-1}dx_n) \in \Gamma.$$

We assume that, for a neighborhood U_1 of \dot{q} , the only one integral curve $b_{\lambda_1}^{(1)}$ of $\partial/\partial x_1$ and the only one $b_{\lambda_2}^{(2)}$ of $\partial/\partial x_2$ pass U_1 . We assume, for simplicity, that the both two curves pass \dot{q} :

$$\dot{q} \in b_{\lambda_j}^{(j)} \quad (j = 1, 2).$$

We assume that

$$\text{supp}(u) \cap U_1 \cap \{(x_1, x_2, x'' = 0, \sqrt{-1}dx_n); x_1 < s_1, x_2 > s_2\} = \emptyset$$

and that

$$\text{supp}(u) \cap U_1 \cap \{(x_1, x_2, x'' = 0, \sqrt{-1}dx_n); x_1 > s_1, x_2 < s_2\} = \emptyset.$$

In this situation, if a point

$$\dot{q}' \in \{(x_1, x_2, x'' = 0, \sqrt{-1}dx_n); x_1 < s_1, x_2 < s_2\}$$

does not belong to $\text{supp}(u)$, then it follows from Theorem 2.1 that

$$\text{supp}(u) \cap \{(x_1, x_2, x'' = 0, \sqrt{-1}dx_n); x_1 > s_1, x_2 > s_2\} = \emptyset.$$

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